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Fuzzy linear elastic dynamic analysis of 2D semi - rigid steel frames with fuzzy fixity factors

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ABSTRACT

This paper proposes a fuzzy finite element procedure for dynamic analysis of the planar semi-rigid steel frame structures with fuzzy input parameters. The fixity factors of beam – column and column – base connections, loads, mass per unit volume and damping ratio are modeled as triangular fuzzy numbers. The Newmark-β numerical integration method is applied to determine the displacement of the linear dynamic equilibrium equation system. The α – level optimization using the Differential Evolution (DE) involving integrated finite element modeling is proposed to apply in the fuzzy structural dynamic analysis. The efficiency of proposed approach is demonstrated through some example problems relating to for the twenty – story, four – bay portal frame and twenty-five – story, three – bay concentrically braced frame.

Keywords: steel frame; fuzzy connection; fuzzy structural dynamic; differential evolution algorithm

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1. Introduction

In the dynamic analysis of steel frame structures with semi-rigid connections, rigidity of the connection (or fixity factor of the connection), loads, mass per unit volume, damping ratio … have a significant influence on the time – history response of steel frame structure (Chan and Chui 2000, Ma *et al*. 2013, Kangmin Lee *et al*. 2014, Nguyen and Kim 2014). In practice, however, many parameters like worker skill, quality of welds, properties of material and type of the connecting elements affect the behavior of a connection, and this fixity factor is difficult to determine exactly. Therefore, in a practical analysis of structures, a systematic approach is needed to include the uncertainty in the joints behavior and the fixity factor of a connection modeled as the fuzzy number is reasonable (Keyhani *et al*. 2012). In addition, the uncertainty of input parameters such as the external forces, mass per unit volume and damping ratio are also described in form of the fuzzy numbers (Massa *et al*. 2011).

In recent years, the fuzzy static analysis (Keyhani *et al*. 2012), and the fuzzy stability analysis (Viet *et al*. 2017) for planar steel frame structures with the fuzzy connections have been reported. However, the fuzzy dynamic analysis for determining the fuzzy time – history response by using exact approach has been limited. For the rigid frame, Tuan *et al*. (2015) presented an approach by using Response Surface Method (RSM) for fuzzy free vibration analysis of linear elastic structure in which response surfaces (surrogate functions) in terms of complete quadratic polynomials are presented for model quantities and all fuzzy variables are standardized. The usage of the RSM shows that this approach has effectiveness for the complex structural problems with a large number of fuzzy variables. However, the RSM is only suitable for problems which all fuzzy variables are modeled as symmetric triangular fuzzy numbers. For the problems with non-symmetric triangular fuzzy numbers, the fuzzy structural analysis must use another approach. Anh *et al*. (2014) presented an optimization algorithm for fuzzy analysis by combining the improved Differential Evolution (DE) with the α – level optimization. DE is a global optimization technique, which combines the evolution strategy and the Monte Carlo simulation, and is simple and easy to use (Storn *et al*. 1997 and Mezura-Montes 2013).

In this paper, the fuzzy displacement - time dependency of planar steel frame structure is determined in which the fixity factor, loads, mass per unit volume, and damping ratio are described in the form of triangular fuzzy numbers. A procedure is based on finite element model by combining the α – level optimization with the Differential Evolution algorithm (DEa). The Newmark-β average acceleration numerical integration method is applied to determine the displacements from the linear dynamic equilibrium equation system of the finite element model. A comparison of the natural radian frequencies of the first and second modes of the considered frame between the RSM and the DEa is illustrated by considering the twenty-floor, four-bay portal steel frame structure, in which the fixity factors are modeled as symmetric triangular fuzzy numbers. The obtained results are not significantly different. After that, the proposed procedure is applied to fuzzy dynamic analysis for this frame, in which considering the fuzzy fixity factor at the column – base connection is modeled as non-symmetric triangular fuzzy number. The deterministic results are also compared with ones of the SAP2000 software. Moreover, the computational efficiency and applicability of the